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Composite copings for the perio-overdenture - An in-vitro study

INAUGURAL-DISSERTATION
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vorgelegt von
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To
Victoria
&
my family

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1. Introduction

The perio-overdenture is a development of the conventional root-retained overdenture.[1] The classical design was modified at the beginning of the eighties in order to overcome the high risk of caries of the abutment teeth as well as of gingivitis and consequently periodontitis.[2] The peculiarity of the perio-overdenture is the periodontal-friendly architecture in which the marginal gingiva around the abutment teeth is 360° free of denture base, so that all interdental spaces are open. At the same time, since there is no overconstruction with acrylic resins, indeed just the crown of the abutment teeth is rebuilt. The physiological oral space is not occupied more than necessary and remains free for the other oral structures so that normal function (speech, mastication etc.) is not impaired.[1] The framework design leaves the marginal gingiva free and the patient can - with the prosthesis *in situ* - easily clean the abutment teeth by using interdental brushes, thus resulting in better hygiene.[3,4,5] Therefore, the perio-overdenture is an optimal treatment modality for patients with severely reduced and periodontally compromised dentition.[6]

Originally, the perio-overdenture was attached to the abutment teeth by means of precision attachments soldered to golden copings. The original coping design included a circular bevel, which was later omitted for esthetical reasons, so that only a very thin golden margin became barely visible. This modification was found to be clinically unproblematic, facilitating as well root preparation.[7,8] As further esthetical improvement, especially for patients showing the margins of the golden copings while talking and laughing, the golden copings could be replaced by porcelain-veneered copings with precision attachments. Since 2003, a new method – i.e., the “dentin bonded composite coping with spherical attachment" – has been developed in order to reduce the perio-overdenture costs. Further advantages of this method are an easier assembly and processing, as well as better re-intervention possibilities, such as easier repairs, attachment replacement, and endodontic re-treatments.[9]

Composite copings can be moulded directly in the patient's mouth (direct technique) or in the lab, based on a diagnostic set-up, and afterwards adhesively bonded to the abutment teeth (indirect technique). Both methods were described in detail in 2006.[9] From 2003 to 2008, a clinical study at the University of Zurich gave promising results.[2] Thirty-one patients, aged 48 to 85 years, received 121 copings with spherical attachments: 51 with direct technique, 70 with indirect technique. Eighty copings were constructed with posts and 41 without. The 121 composite copings supported 35 perio-overdentures fixed with 60 Dalbo Plus™ and 61 with Ecco™ retention-grip anchors. Patients were put on a recall program every four months after coping delivery until October 2007. Three (2.5%) abutment teeth in three patients showed a caries lesion and two (1.7%) abutment teeth were extracted for endodontic problems. Pocket depth remained constant throughout the follow-up time. Six out of 121 composite copings were fractured and six debonded *in toto*. Five out of six fractures occurred in the coping constructed in the lab. Also four out of six debonded copings had been constructed in the lab. Three out of six debonded and five out of six fractured copings had a post. The six fractures and six debondings occurred in eight patients. Two of them had both types of failure. The 12 coping failures occurred between seven months and 2.5 years post insertion. Within the limits of this study, a conclusion may be drawn: adhesively bonded composite copings have a high success rate at short/middle term;

they can be possibly constructed without a post. Long-term studies are needed to confirm whether this high success rate (90.0 %) is long-lasting.

So far, many questions have remained unanswered. It is still unknown 1) how good the adhesion of the composite copings with spherical attachment to the abutment tooth is; 2) whether the root dimension and the following amount of dentin surface is relevant for an optimal long-term stress resistance; 3) whether a post is really needed to reach the treatment success. In order to answer these questions we developed an *in vitro* study.

The aim of this work was therefore twofold: 1) to compare composite copings with and without intracanalar passive posts (GP-Ball® with and without post); 2) to compare the alternative cementing methods of the intracanalar posts, either with a resin composite luting cement or with a glas-ionomer cement.

2. Materials and methods

2.1. Tooth selection

For this study, 81 extracted upper and lower canines previously stored in tap water were used (Fig. 1.1). The anatomical crown of each tooth was removed using a diamond disk. Only the root with open canal remained (Fig 1.2). In the apical part of each tooth, some small furrows were carved for mechanical retention by means of a cylindrical diamond bur (Intensiv SA, Switzerland) (Fig. 1.3). The roots were then embedded in a cylindrical resin mass (Paladur®; Heraeus, Germany) (Fig. 1.4). The major and minor axes of the elliptical occlusal tooth surface were then measured with a calliper in order to estimate the exposed upper dentin surface. The prospective adhesion surface was estimated using the ellipse surface formula (Fig.2).

The teeth were randomly divided into three groups. They were defined as follows:

Group I	33 composite copings with spherical attachment (GP-Ball®, Fig. 3) with post. Cementation with resin composite luting cement (Variolink® II, Ivoclar Vivadent, Principality of Liechtenstein).
Group II	15 composite copings with spherical attachment (GP-Ball®) with post. Cementation with glas-ionomer cement (Ketac® Cem, 3M ESPE, USA).
Group III	33 composite copings with spherical attachment (GP-Ball®) without post. Preparation of tooth by canal inlay. Cementation with resin composite luting cement (Variolink® II, Ivoclar Vivadent, Principality of Liechtenstein).

2.2. Specimen preparation

In all specimens the dentin surface was conditioned using first the Syntac Primer® and then Syntac Adhesive® and moistened with Heliobond® (Ivoclar Vivadent AG, Principality of Liechtenstein), followed by LED curing light for 60 seconds (Blue Phase®, Ivoclar Vivadent AG, Principality of Liechtenstein). All GP-Ball® attachments below the upper limit of the composite mark (Fig. 3) were treated first by sandblasting (Rocatec®, 3M ESPE, USA) providing a silicate coat and then silanised (Monobond S®, Ivoclar Vivadent AG, Principality of Liechtenstein).

Group I. The root canal was enlarged to a depth of 4 mm until a GP-Ball® with post could be inserted frictionlessly (Fig. 4.2). The GP-Balls® were cemented adhesively by means of the dual-curing resin composite luting cement Variolink® II (Ivoclar Vivadent AG, Principality of Liechtenstein) (Fig. 4.3). Cement excesses were eliminated and chemical hardening was accelerated by light curing. The copings were directly moulded up to the mark of the GP-Ball® with fine-hybrid composite (Tetric®, Ivoclar Vivadent AG, Principality of Liechtenstein) and light cured for 60 seconds (Fig. 4.4).

Group II. Similarly to group I, the root canal was enlarged to a depth of 4 mm until a GP-Ball® with post could be inserted frictionlessly. In contrast to Group I, the cementation occurred with glas-ionomer cement (Ketac® Cem, 3M ESPE, USA). The copings were directly moulded up to the mark of the GP-Ball® with fine-hybrid composite (Tetric®, Ivoclar Vivadent AG, Principality of Liechtenstein) and light cured for 60 seconds.

Group III. Differently than in groups I and II, in the specimens of group III, instead of enlarging the root canal, a canal inlay (diameter ~3 mm, depth 2-4 mm) was prepared with a diamond bur (Intensiv SA, Grancia, Switzerland) (Fig. 5.2). The copings were constructed indirectly with the aid of a silicon template and a flowable composite (TetricFlow®, Ivoclar Vivadent AG, Principality of Liechtenstein) (Fig. 5.3). Light curing occurred again for 60 seconds. After silanisation of the composite surface, the copings were cemented to the tooth with Variolink® II (Fig. 5.4). Cement excesses were eliminated and chemical hardening was accelerated with a LED curing light for 60 seconds. Coping borders were then re-contoured using cylindrical diamond burs (Intensiv SA, Grancia, Switzerland) and discs (Soft-Lex®, 3M ESPE, USA).

2.3. Mechanical tests

Compression. Specimens were inserted in the sample chambers of a computer-controlled, custom-made masticator (construction by the University of Zurich),[10] which had twelve places available. Therefore, seven runs were needed to test all 81 samples. About 1,200,000 compressions cycles were needed for the simulation of a composite coping wear of 5 years in the patient's mouth. Forces of 50 N magnitude acted axially and directly on the spherical attachment. Each run of 1,200,000 cycles lasted slightly longer than 9 days. After this compression test, all 81 samples were examined for detection of possible damage to the root or to the composite coping.

Traction. Each specimen was then stressed to failure by clasping it in a computer-controlled tractional machine (Zwick Universalmaschine, Zwick GmbH & Co., Ulm, Germany). A custom-made metal matrix gripped the ball attachment and pulled with an increasing force until the tension suddenly dropped. This drop indicated a fracture inside the sample (resin-root-composite-spherical attachment-complex). The maximum tension developed ("ultimate strength") as well as the rupture sites were then noted.

Failures were classified as previously described (Fig.7):[11, 12]

A) adhesive failure:	the fracture site was contained within the adhesive (coping and tooth intact), "debonding".
B) mixed failure:	the fracture site started in the adhesive and continued into either dentin or resin.
C) substrate failure:	the fracture occurred within the dentin or within the resin.
D) invisible failure:	any failures not showing any macroscopic observable damage

In case of failure class "B" or "C", a distinction between dentin and resin was necessary.

2.3. Statistical analysis

The mean and standard deviation of the maximum tractional force were calculated for each group. Additional descriptive statistics regarding the rupture site and failure classes was done. In particular, dentin involvement in substrate fractures was quantified. Comparisons between the amount of dentin surface and maximum tractional force were conduced. Scheffé tests at a significance level of 5% were used in order to compare the groups I to III according to their ultimate strength.

3. Results

3.1 Compression test

After 1,200,000 compressive cycles, none of the 81 specimens was damaged. Neither fractures nor fissures nor loosening of the spherical attachments were observed.

3.2 Traction test

For Group I, the occlusal surface was 31.3 ± 5.1 mm^2 and the ultimate strength (tractional force leading to failure) was 274.2 ± 147.1 N (Table 1). In the 33 specimens, twelve (36.4%) adhesive failures (class “A”), eight (24.2%) mixed failures (class “B”), and eleven (33.3%) substrate failures (class “C”) were observed. Across all classes, in 15 (45.4%) specimens, dentin was fractured. In five (15.15%) cases, the composite coping was damaged. Two specimens had invisible fractures (class “D”).

For Group II, the occlusal surface was 33.8 ± 8.8 mm^2 and the ultimate strength was 119.8 ± 54.3 N (Table 3). In the 15 specimens, eleven (73.3%) failures were adhesive (class “A”). Only one mixed failure (class “B”) led to dentin fracture (6.6%), whereas the remaining three cases showed no macroscopic damages (class “D”).

The occlusal surface for Group III was 33.2 ± 7.0 mm^2 and the ultimate strength was 230.2 ± 54.3 N (Table 5). In the 33 specimens, thirteen (39.4%) failures were adhesive (class “A”), thirteen (39.4%) mixed (class “B”) and four (12.1%) in the substrate (class “C”). Across all classes, eight (24.2%) dentin fractures were observed, whereas in ten (30.3%) cases the composite coping was damaged. Three specimens had no macroscopic damages (class “D”).

R^2 of 0.001 for Group I, 0.198 for Group II and of 0.001 for Group III failed to show an overall association between the amount of dentin surface and the ultimate strength measured by the machine (Graphics 9,10,11).

One-way ANOVA showed a significant difference among groups I to III regarding ultimate strength (p=0.0004). By subjecting Group I and III to a Scheffé-test, a p-value of 0.3348 resulted, not statistically significant. Therefore, the composite copings with GB-Ball® respectively with and without post, if cemented adhesively with Variolink® II, were similar with regard to the maximum tractional force. The same test for groups I vs. II and II vs. III gave a p-value of 0.0004 resp. 0.0158, thus being statistically significant. Therefore, GP-Ball® composite copings with post cemented with glasionomer cement Ketac® Cem showed a significantly lower maximum tractional force leading to failure compared to adhesively cemented copings.

4. Discussion

The high standard deviations showed a wide variability in maximum tractional forces, especially for Group I. It can be supposed that the different amount of dentin surface plays a role. Each root has a different size and to be compared, the microtensile bond strength should be calculated (F_{max}/dentin surface). Group I showed a mean value of 8.77 N/mm^2 (MPa), Group II of 3.54 N/mm^2 (MPa) and Group III of 3.64 N/mm2 (MPa). In the literature dentin bond strength mean values of 20.20 MPa for Syntac®/Tetric® Ceram System and between 15.1 and 39.2 MPa for Syntac®/Variolink®II System are described.[13,14,15] These values are higher than the measured mean maximum forces. Furthermore, the coefficients of determination R^2 failed to show an overall association between the amount of dentin surface and the maximum tractional force measured by the machine. An earlier adhesive failure is difficult to explain. Typical well-known compromising factors are:[16, 17,18]

- to long or inappropriate stocking of materials
- water contamination (in vivo with saliva), oil, drill dust or glove dust
- air bubble incorporation (especially by chemical hardening two-paste systems, like Variolink®II)
- prior partial hardening by stray light
- uncompleted hardening
- destructive finishing

Most of these factors are of secondary relevance, given that the experimental circumstances prevalently allow optimal operative techniques (perfect view, no saliva, no time stress, desire for good results,...). A possible reason for this wide variability could be the imperfect axial straightened traction. Actually it was impossible to pull the spherical attachment always in the right direction, when respecting the exact post's axis. The angle between this axis and the effective pull direction may be different for each specimen and is a further variable which is impossible to follow. An increased pull angle could perhaps more easily conduce to failure, due to additional mechanical stress of the post on dentin. All this makes a comparison of the results of this study with other tractional test in the literature very difficult; on the other hand the comparison with the clinical aspects is easier. Actually, in the patients' mouths perfect axial working tractional forces are very rare and of low values: about 12-18 N in the case of sticky food[19] and in range of 3-12 N in order to separate a matrix from the most spherical attachments.[20] In our study the mean in vitro measured tractional forces are higher then these mentioned in vivo forces. At such a high tractional force, the matrix would first separate itself form the spherical attachment, before any fracture could happen.

The statistical analysis allows a comparison between different cementation (glasionomer cement vs. resin composite luting cement) and between absence or presence of a passive post. The best resistance of full adhesive cemented compared to spherical attachment cemented with glasionomer should be obvious, but a more interesting result has to be noted: the lower number of dentin fractures of Group II compared to Group I. Furthermore, Group I and Group III are for the maximum tractional forces statistically comparable. Consequently, the presence or the absence of a post could have only marginal or even no relevance for an appropriate adhesion of the whole composite coping to the root. The low dentin fractures of Group III (21% less than Group I) and the following more rare loss of dentin substrate, lead to think that in the clinical cases composite copings without a post could have better, easier and cheaper repair possibilities; this would mean a longer life of the abutment teeth and, consequently, of the whole reconstruction.

Limits of this study

Like each in-lab study, this one has many limits; each difference between in-vitro circumstances and a real patient could complicate the projection in clinical practice. Some of these disparities are:

in vitro	**in vivo**
only canines (upper and lower)	many teeth
no endodontic treatment before the specimen preparation	endodontic treatment with possibly different preparation and fill techniques, different operator
absolutely dry conditions easy to attain	absolutely dry conditions partially difficult to reach
only one direction of the acting force during the simulation in the masticator	many force directions
compression force acts directly on the spherical attachment	chewing forces act first on the prosthesis and only indirectly on the spherical attachment
rather axial working tractional forces (as good as possible)	a) mostly extra axial working forces b) pure axial working forces only by removing the prosthesis.

Outcome for clinical practice

As already described in 2006,[9] the composite copings are an easy and cost-effective alternative to the conventional gold copings used in perio-overdentures. A short term clinical study gave good results. This in-vitro study confirms the clinical experience, inasmuch as an experimental compression stress of 5 equivalent years in the patient's mouth has as result no damage of the composite copings. Also the mean measured maximum tractional forces are higher than the equivalent in-vivo really acting forces. All this speaks out for a successful employment of composite copings as anchor alternatives for the perio-overdenture. Clinical long term studies are at the moment unavailable, but they are needed to confirm the success over a long period of time. Very important is the differentiation between abutment tooth survival and coping survival. In this respect the easy, quick and cost-effective repair possibilities are considerable advantages of the composite copings compared to the conventional golden copings. The employment of a spherical attachment without post could be a further meaningful development, given that this study showed a lower dentin fracture rate using spherical attachments without post compared to those with a post, despite the comparable bond strength. However, at the moment a wide employment of this last advancement is not yet recommendable, because of the very reduced clinical experience.

5. Summary

The perio-overdenture is a development of the conventional root retained hybrid prosthesis. The denture base does not cover the marginal gingiva and the periodontal-friendly reconstruction of the abutment teeth leaves the interdental spaces open.

The original attachment with golden copings can be replaced by adhesively cemented composite copings with spherical attachment (in our study: GP-Ball®). The short term, very promising clinical experience should be completed by an *in vitro* study, in order to evaluate: how good the adhesion of the composite copings to the abutment tooth is, the differences between cementation with glasionomer (Ketac® Cem) and a resin composite luting cement (Variolink® II), whether a post is really needed, and whether a minimum dentin surface is necessary.

81 extracted upper and lower canines were divided into three groups and prepared for a composite coping according to following group characterisation: *Group I*: 33 teeth prepared with GP-Ball® with post, cementation with Variolink® II; *Group II*: 15 teeth prepared with GP-Ball® with post, cementation with Ketac® Cem; *Group III*: 33 teeth prepared with GP-Ball® without post, cementation with Variolink® II. The specimen were tested first for compression in a masticator and then, in a tractional machine, stressed to failure. The maximal forces reached were noted as well as the rupture site. The values were statistically analyzed with one-way ANOVA and Scheffé-test.

After 1,200,000 compressions, none of the 81 specimens was damaged. Neither fractures, nor fissures nor loosening of the spherical attachments were observed. The tractional force leading to

failure was 274.2 ± 147.1 N for Group I, 119.8 ± 54.3 N for Group II, 230.2 ± 54.3 N for Group III. Group I and Group III are for the maximum tractional forces statistically comparable whereas Group II was significantly different. In Group I more dentin fractures were observed than Groups II and III. R^2 showed an overall non-significant association between the amount of dentin surface and the maximum tractional force.

The mean *in vitro* measured tractional forces were higher than in vivo really acting forces. Nevertheless, in spite of the high standard deviations and the limits of this study, it is possible to observe that the presence or the absence of a post could have only marginal or even no relevance for an appropriate adhesion and that attachment without post could have a better prognosis, due to the lower dentin fracture rates.

6. Zusammenfassung

Die Perio-Overdenture ist eine Weiterentwicklung der konventionellen Hybridprothese. Durch die offene Basisgestaltung wird die marginale Gingiva nicht bedeckt.

Die ursprüngliche Verankerung mittels Goldkappen kann mit Kompositkappen mit Kugelanker ersetzt werden (in unserer Studie: GP-Ball®). Die kurzzeitige aber vielversprechende klinische Erfahrung musste mit einer *in vitro* Studie ergänzt werden. Die Ziele waren die Evaluation der Kompositkappenadhäsion, der Unterschiede zwischen Zementation mit Glasionomer- (Ketac® Cem) und mit Kompositzement, ob ein Stift wirklich notwendig ist, und ob eine minimale Dentinoberfläche notwendig ist.

81 extrahierte obere und untere Eckzähne wurden in drei Gruppen unterteilt und für Kompositkappen präpariert, entsprechend der Gruppeneigenschaften. *Gruppe I*: 33 mit Stift versorgten GP-Ball®, Zementierung mit Variolink®II; *Gruppe II*: 15 mit Stift versorgten GP-Ball®, Zementierung mit Ketac® Cem; *Gruppe III*: 33 stiftlose GP-Ball®, Zementierung mit Variolink®II. Die Proben wurden zuerst in einem Kausimulator getestet (Kompressionsversuch); dann wurden sie in einer Abzugsmaschine bis zum Bruch unter Spannung gestellt (Abzugsversuch). Die maximale gemessene Abzugskraft, sowie die Bruchstelle wurden beobachtet und notiert. Die Werte wurden mit einfaktorieller ANOVA und Scheffé-Test verglichen.

Keine der 81 Proben war nach 1’200’000 Kompressionen beschädigt. Weder ein Bruch, noch ein Riss, noch eine Lockerung der zementierten Patrizen liessen sich feststellen. Die maximalen gemessenen Abzugskräfte waren 274.2 ± 147.1 N für Gruppe I, 119.8

± 54.3 N für Gruppe II, 230.2 ± 54.3 N für Gruppe III. Gruppe I und III waren bezüglich Abzugskräfte statistisch vergleichbar, während sich Gruppe II signifikant unterschied. In der Gruppe I wurden mehr Dentinfrakturen als in Gruppe II und III beobachtet. R^2-Koeffizienten konnten keinen Zusammenhang zwischen Dentinoberfläche und maximale Abzugskraft beweisen.

Die gemessenen maximalen Kräfte waren höher als die im Mund tatsächlich wirkende Kräfte. Trotz hohen Standardabweichungen und den Limiten dieser Studie, stellt sich die Frage ob ein Stift für die optimale Haftung der Kompositkappe wirklich notwendig ist. Ein Ankerelement ohne Stift könnte wegen der tieferen Dentinfrakturrate zu einer besseren Langzeitprognose führen.

7. Figures

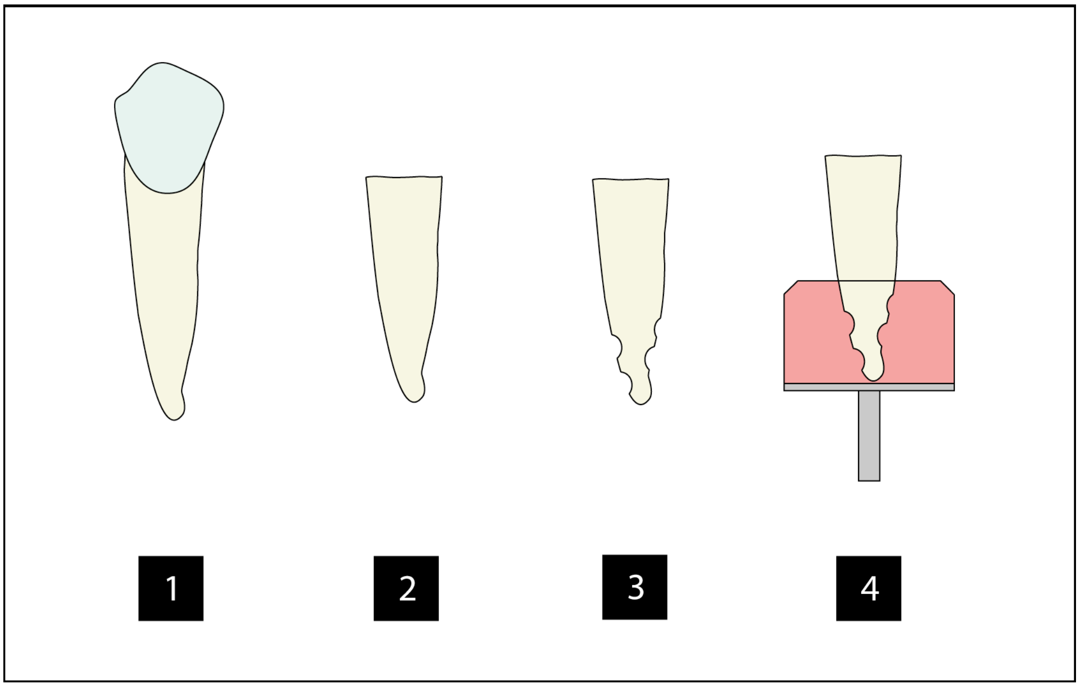


Fig.1: Uncut canine ①. The anatomical crown was removed ②. Some small furrows were done with a cylindric diamond bur ③. The roots were then embedded in a cylindric resin mass ④.

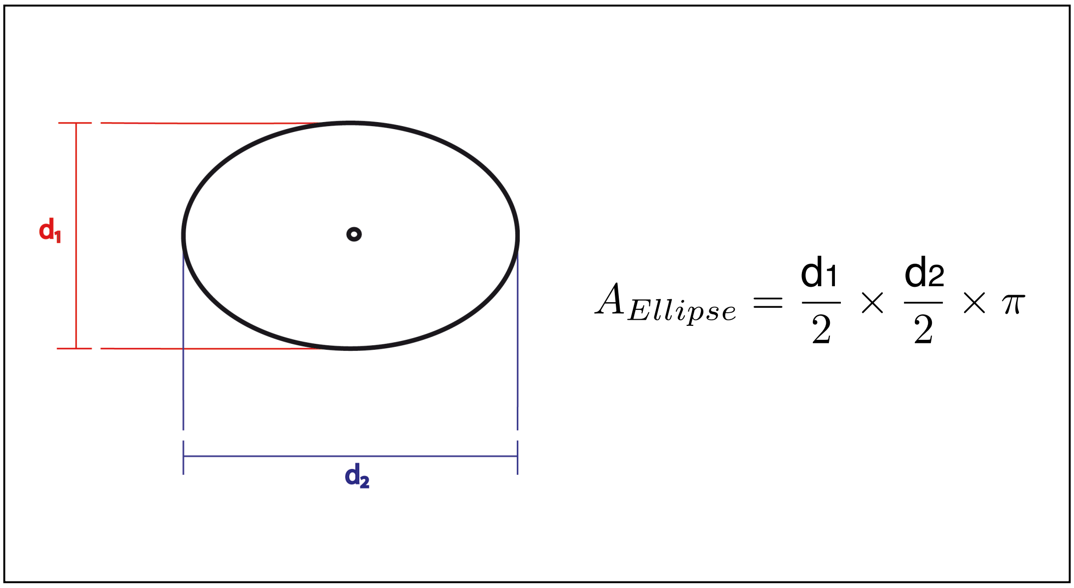


Fig.2: The major and minor axes of the elliptical occlusal tooth surface were measured with a calliper in order to estimate the exposed upper dentin surface.

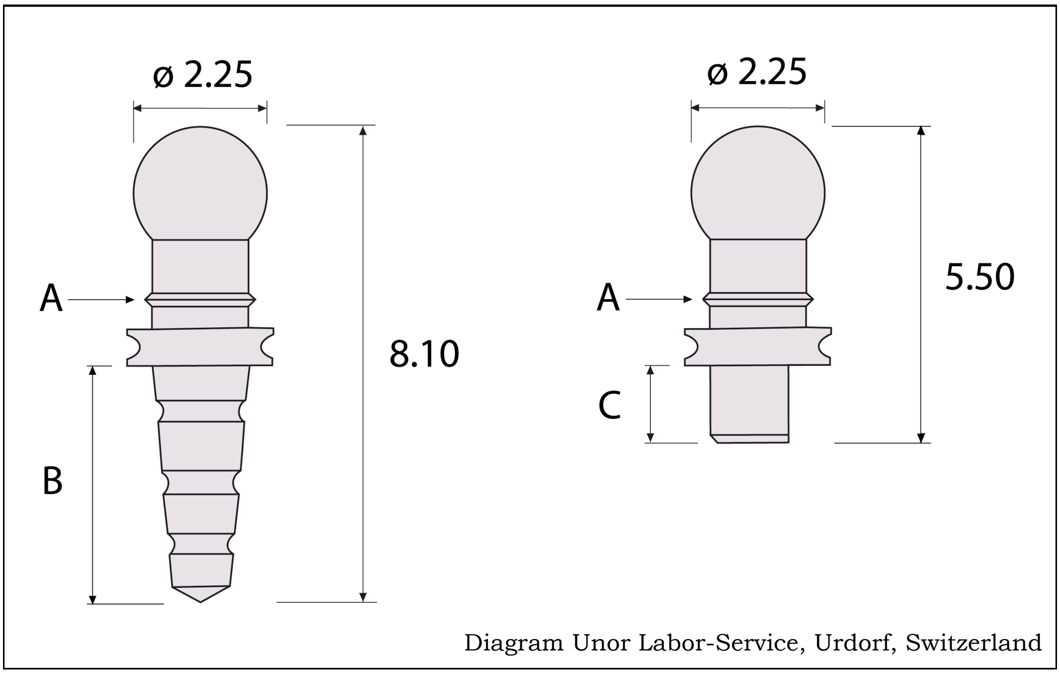


Fig.3: GP-Ball® with and without post (Unor Labor-Service, Urdorf, Switzerland). **A:** Upper limit for the composite; **B:** 4 mm ; **C:**1.60 mm

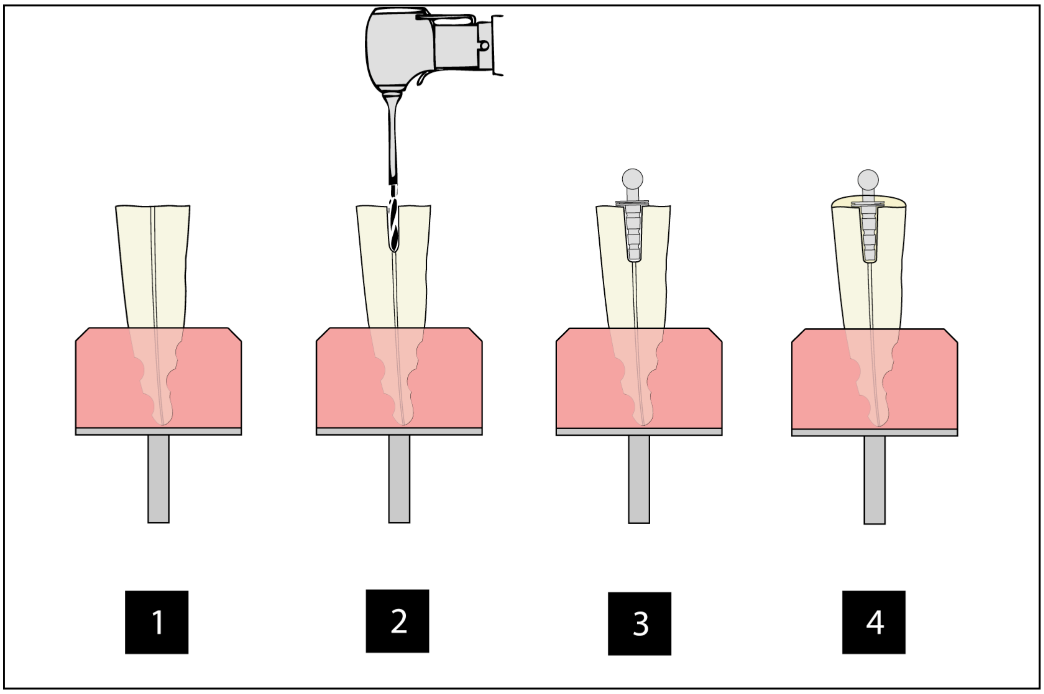


Fig.4: Teeth of Group I and II. The root canal was enlarged to a depth of 4 mm ②. The post was cemented (Group I, Variolink®II; Group II, Ketac® Cem) ③. The copings were directly moulded with fine-hybrid composite ④.

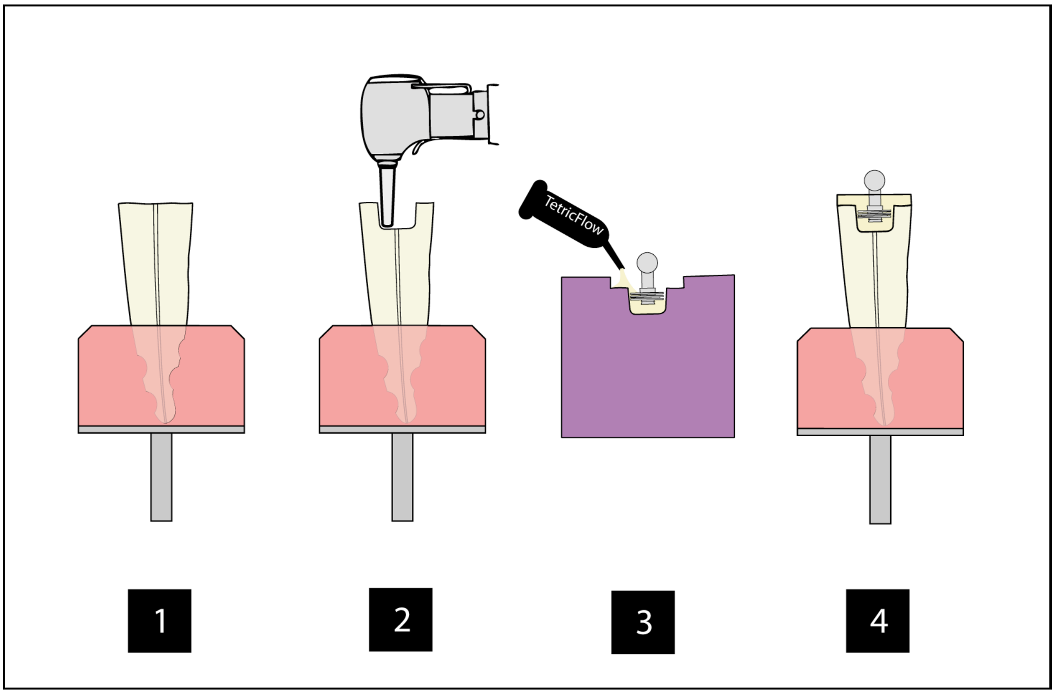


Fig.5: Teeth of Group III. A canal inlay (about 3 mm of diameter, 2-4 mm deep) was prepared ②. The copings were indirectly constructed with aid of a silicon template and a flowable composite ③. The copings were cemented with Variolink® II ④.

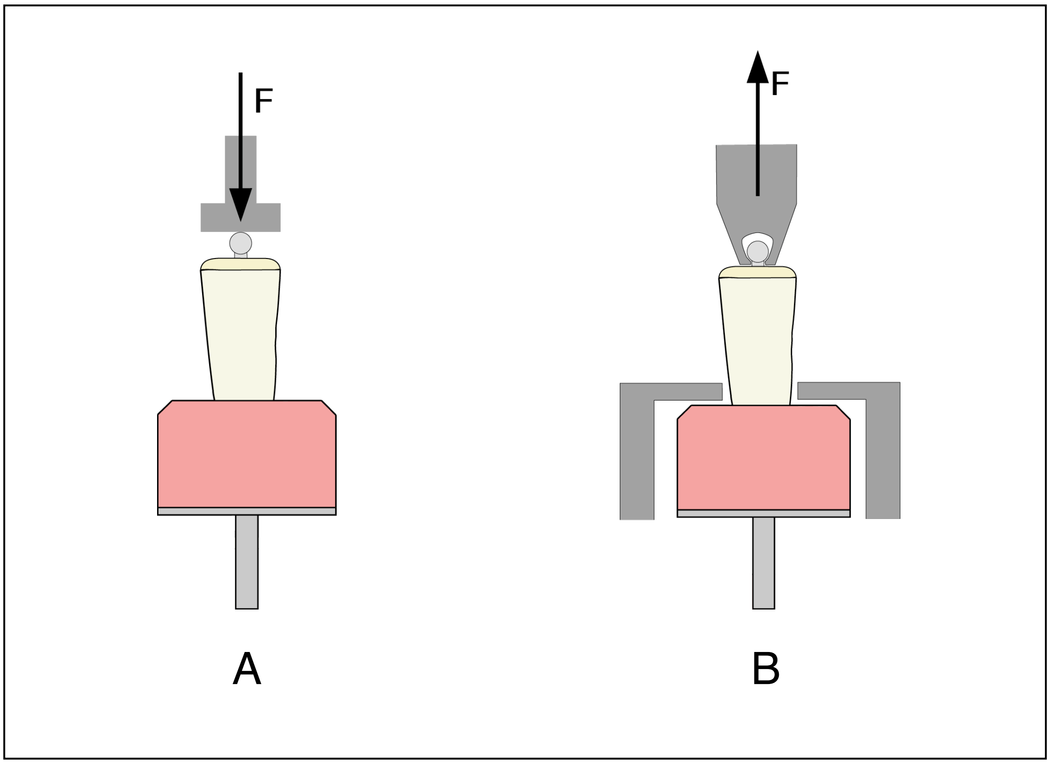


Fig.6: A: Compression test; **B**: Tractional test

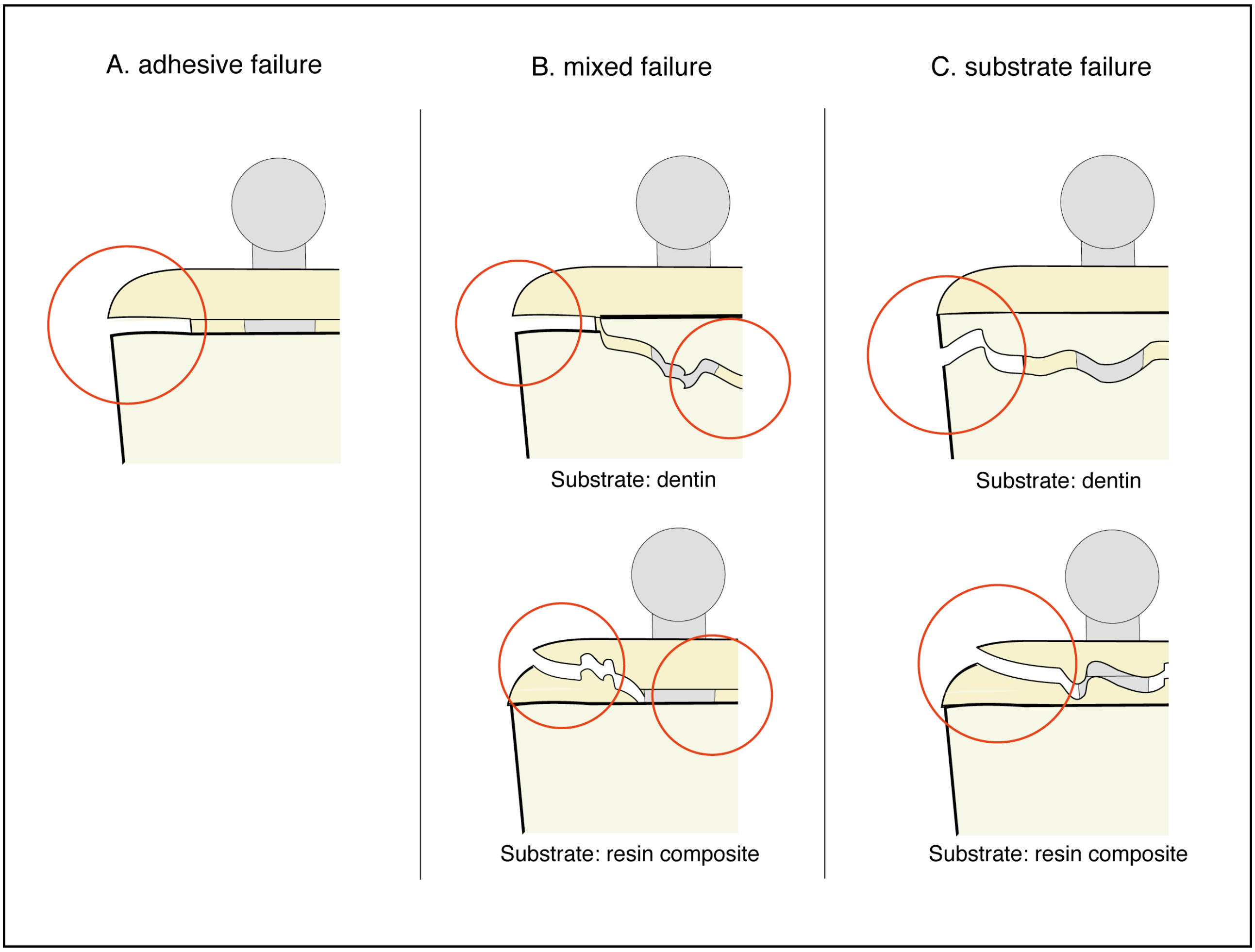


Fig.7: Failure classes

8. Tables and graphics

Table 1. Group I

D.1	D.2			Surface (mm^2)	F_{max} (N)	Failure class
7.6	4.5			26.85	82.92	a
7.2	4.8			27.13	182.97	a
6.4	5.4			27.13	620.34	b (substrate: dentin)
8	6			37.68	427.03	a
8.2	5.6			36.05	76.81	a
7.6	4.6			27.44	461.34	c (substrate: dentin)
7	4.4			24.18	373.31	a
7.2	4.9			27.69	419.67	c (substrate: dentin+composite)
7.5	4.6			27.08	147.1	a
7.6	4.9			29.23	317.65	c (substrate: dentin)
6.9	4.5			24.37	333.23	a
7.3	4.9			28.08	145.07	a
8	5.8			36.42	472.85	b (substrate: dentin)
8.2	5.2			33.47	496	b (substrate: dentin)
7.8	5.7			34.90	42.88	d
7.5	5.8			34.15	231.08	d
7.1	5			27.87	290.48	c (substrate: composite)
7	5.5			30.22	255.92	a
7.2	5			28.26	305.74	c (substrate: composite)
8.9	6			41.92	295.63	c (substrate: composite)
7.5	6.3			37.09	148.34	a
8.1	5.3			33.70	115.3	a
7.4	4.9			28.46	22.66	b (substrate: dentin)
6.4	5			25.12	309.62	c (substrate: dentin)
9	6			42.39	409.45	a
8.2	5.1			32.83	230.1	b (substrate: dentin)
7.7	5.4			32.64	417.02	c (substrate: dentin)
7.8	6			36.74	269.57	b (substrate: dentin)
6.7	4.7			24.72	23.39	c (substrate: dentin)
7	4.6			25.28	339.94	c (substrate: dentin)
8.2	5.8			37.33	230.19	b (substrate: dentin)
8.2	4.7			30.25	280.72	c (substrate: composite)
8.1	5.5			34.97	273.34	b (substrate: dentin)
mean values:				31.3 ± 5.1	274.2 ± 147.1	

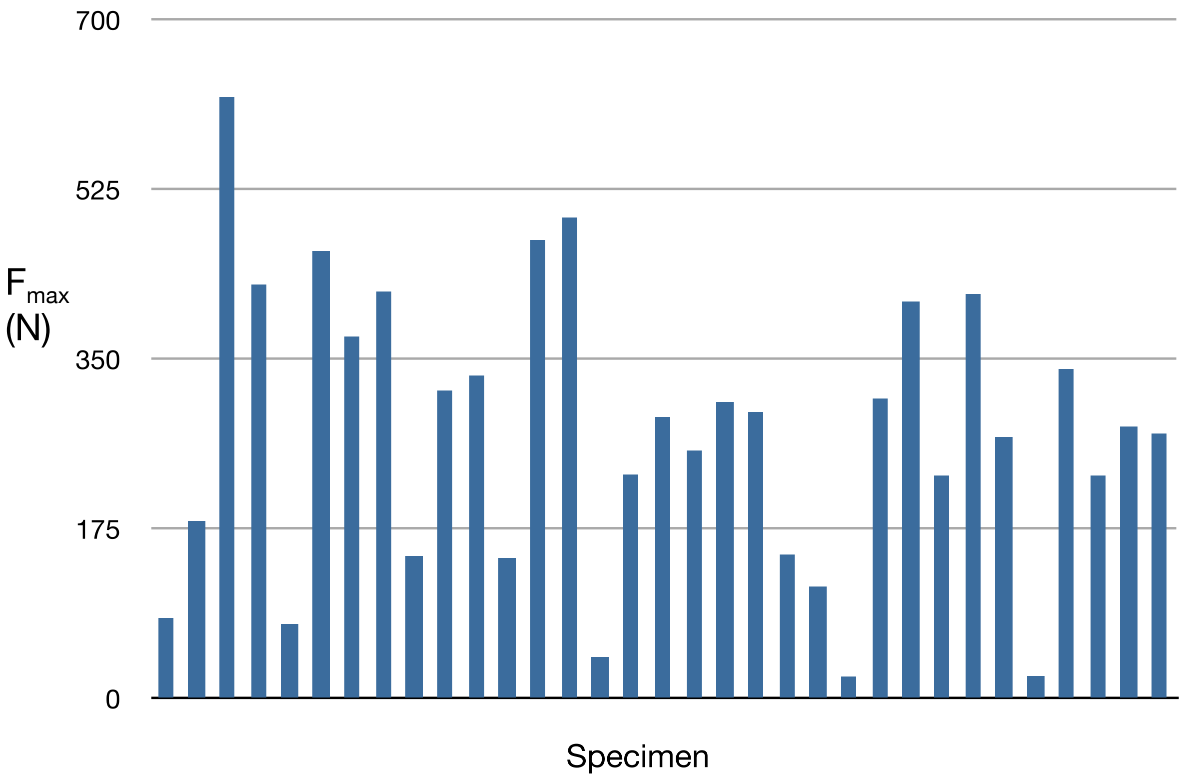
Table 2. Group I - Cumulative failure classes (and subclasses)

Failure class

Substrate

	a	b	c	d
	12			2
Dentin		8	6	
Dentin+Composite		0	1	
Composite		0	4	

Graphic 1. Group I - maximum reached tractional forces.



Graphic 2. Group I - Estimated dentin adhesive surfaces in relation to the maximum reached tractional forces.

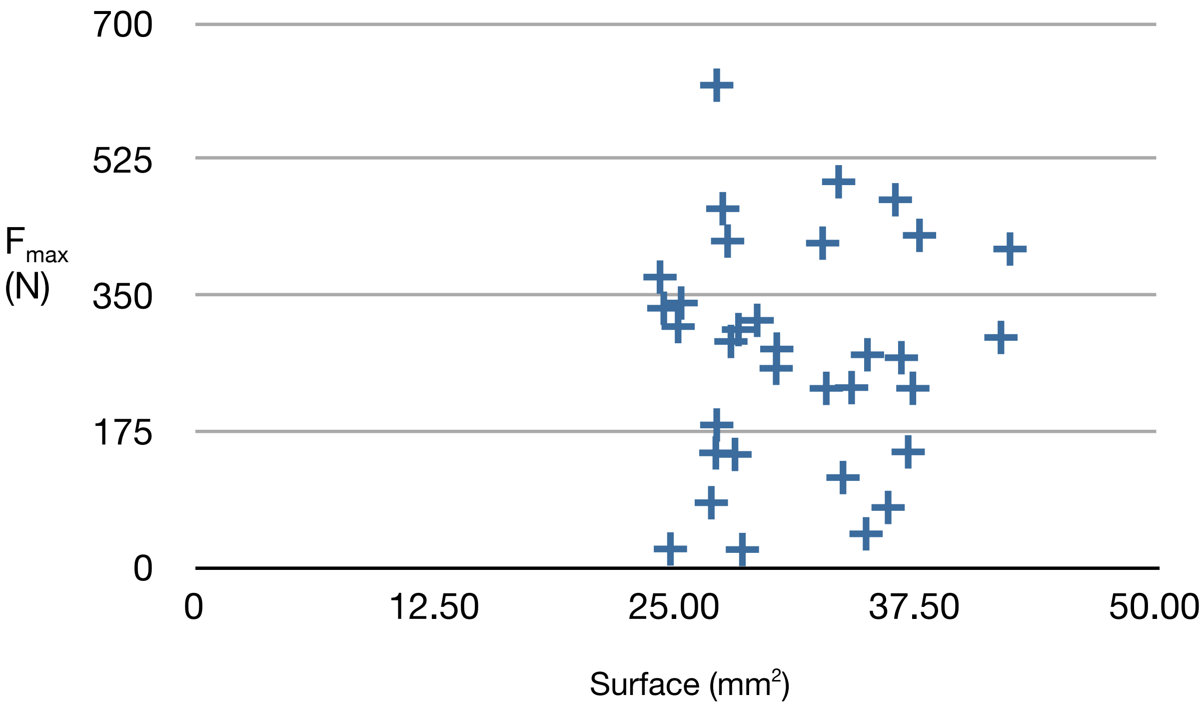


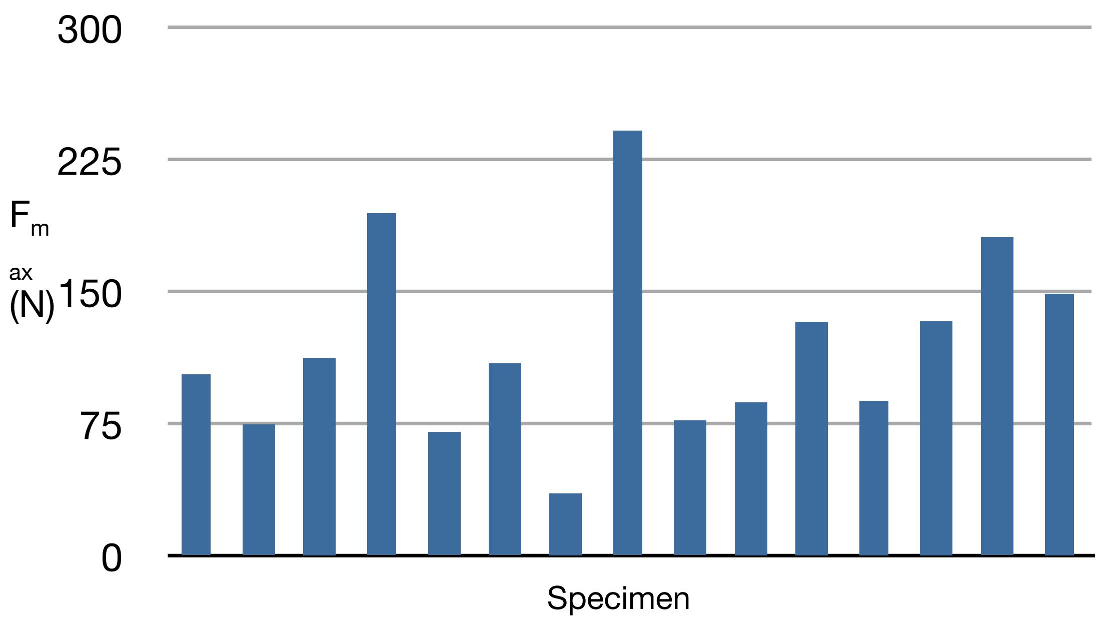
Table 3. Group II

D.1	D.2	Surface (mm^2)	F_{max} (N)	Failure class
6.7	5	26.30	103.49	a
7.4	4.4	25.56	75.17	a
8	4.5	28.26	113	a
7.5	4.8	28.26	195.04	b (substrate: dentin)
7.2	5.3	29.96	70.84	a
6.9	4.6	24.92	109.72	a
7.2	5.7	32.22	36.04	a
8.8	5.7	39.38	241.91	a
7	5.2	28.57	77.33	a
6	8.7	40.98	87.71	a
8	5.5	34.54	133.45	d
8.5	5	33.36	88.56	d
7.7	5.9	35.66	133.72	d
10.7	7.1	59.64	181.37	a
8.4	5.9	38.90	149.35	a
mean values:		33.77 ± 8.8	119.78 ± 54.3	

Table 4. Group II - Cumulative failure classes (and subclasses)

Substrate	Failure class: a	b	c	d
	11			3
Dentin		1	0	
Dentin+Composite		0	0	
Composite		0	0	

Graphic 3. Group II - maximum reached tractional forces.



Graphic 4. Group II - Estimated dentin adhesive surfaces in relation to the maximum reached tractional forces.

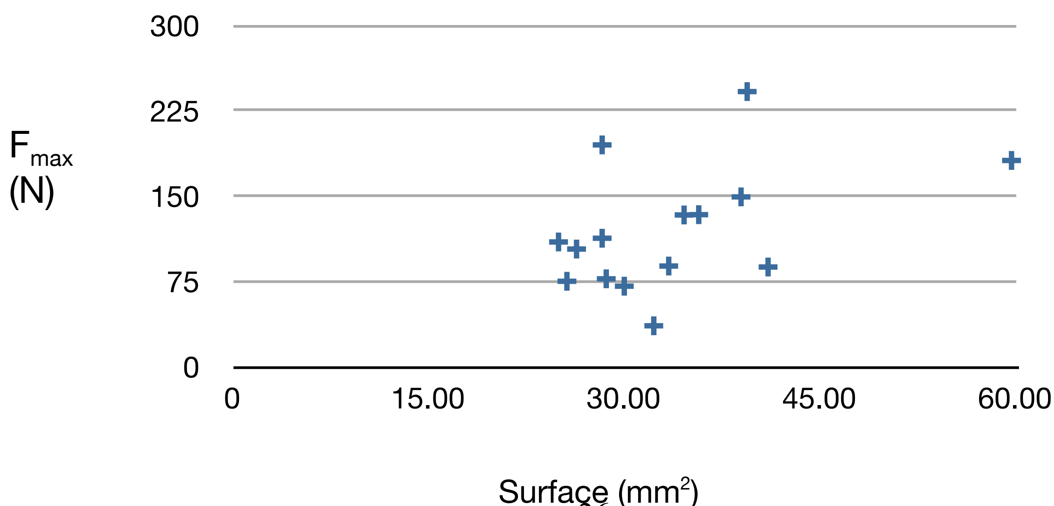


Table 5. Group III

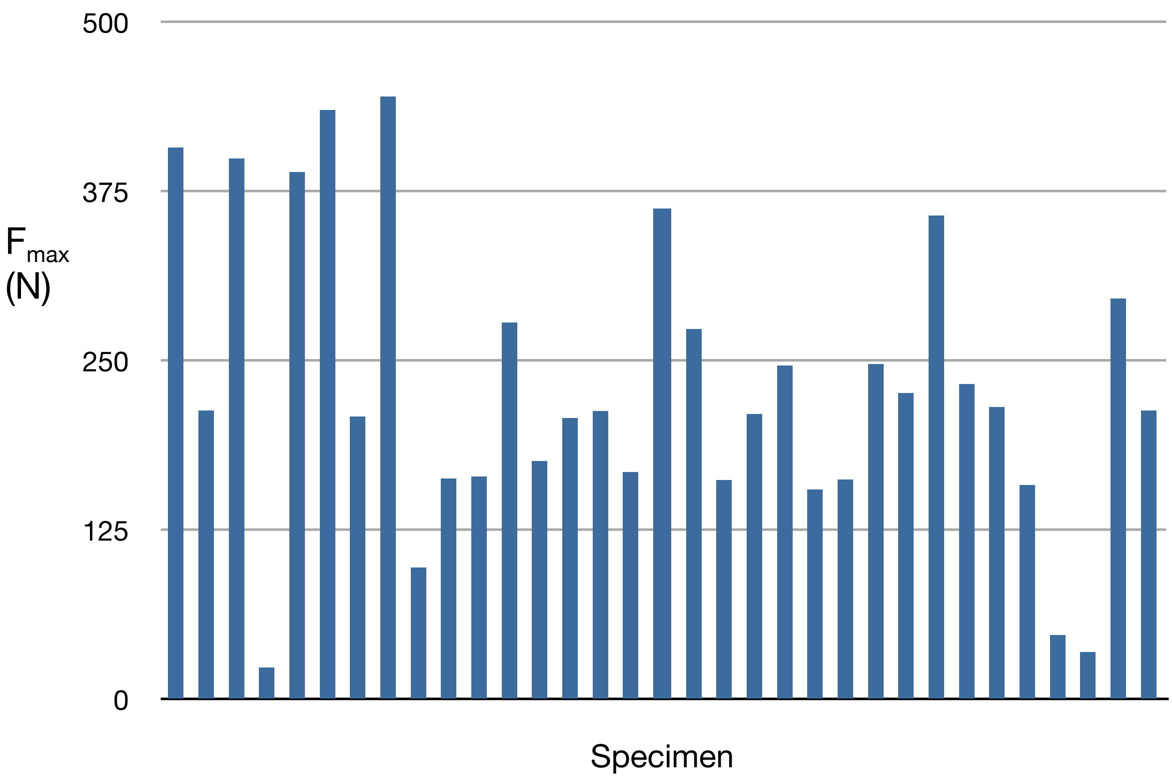
D.1	D.2	D. Inlay	Deep	Surface (mm^2)	F_{max} (N)	Failure class
7.3	4.7	2.8	1.5	26.93	407.55	c (substrate: composite)
7.3	5.5	3.3	1.5	31.52	213.55	a
8.2	5.5	2.9	1.5	35.40	399.62	a
7.8	5.7	3.2	1.5	34.90	23.81	a
7.9	5.6	3.1	1.5	34.73	389.6	a
7.2	5.4	2.9	1.5	30.52	435.47	b (substrate: dentin)
6.6	5.3	3.1	2	27.46	209.02	a
7.9	5.6	2.8	1.5	34.73	445.16	b (substrate: dentin)
8.5	5	3.1	1.5	33.36	97.43	a
7.3	4.6	2.8	1.5	26.36	163.24	a
6.9	4.8	3	2	26.00	164.74	b (substrate: dentin)
7.8	5.9	3.5	2	36.13	278.51	c (substrate: composite)
6.4	9.6	3.5	2	48.23	176.1	a
7.7	5.5	3.5	2	33.24	207.83	d
8	5.4	3.5	2	33.91	213.11	a
7.8	5.4	3	4	33.06	168.06	b (substrate: composite)
7.5	5.5	3.7	4	32.38	362.52	b (substrate: composite)
9	6.4	3	4	45.22	273.49	b (substrate: composite)
7.6	4.7	3.5	4	28.04	162.1	b (substrate: dentin)
8	5.5	3.2	4	34.54	210.95	d
7.2	4.6	3	4	26.00	246.53	b (substrate: dentin)
7.2	8.2	3.8	4	46.35	154.97	b (substrate: composite)
7	4.6	2.9	4	25.28	162.51	a
7.4	5.2	3.5	4	30.21	247.61	c (substrate: composite)
9.7	7.3	4	4	55.59	226.42	a
7.7	5.2	3.2	4	31.43	357.28	b (substrate: composite)
8.3	6	3	4	39.09	232.9	b (substrate: composite)
7.1	5.3	3.3	4	29.54	216.1	a
7.5	5.7	2.9	4	33.56	158.47	c (substrate: dentin+composite)
7	5.2	3.2	4	28.57	47.75	b (substrate: dentin)
7.5	4.8	3.3	4	28.26	35.23	d
7.3	4.7	3	4	26.93	296.2	b (substrate: dentin)
7.4	4.7	3.4	4	27.30	213.47	a

mean values:	33.2 ± 7.0	230.2 ± 109.9

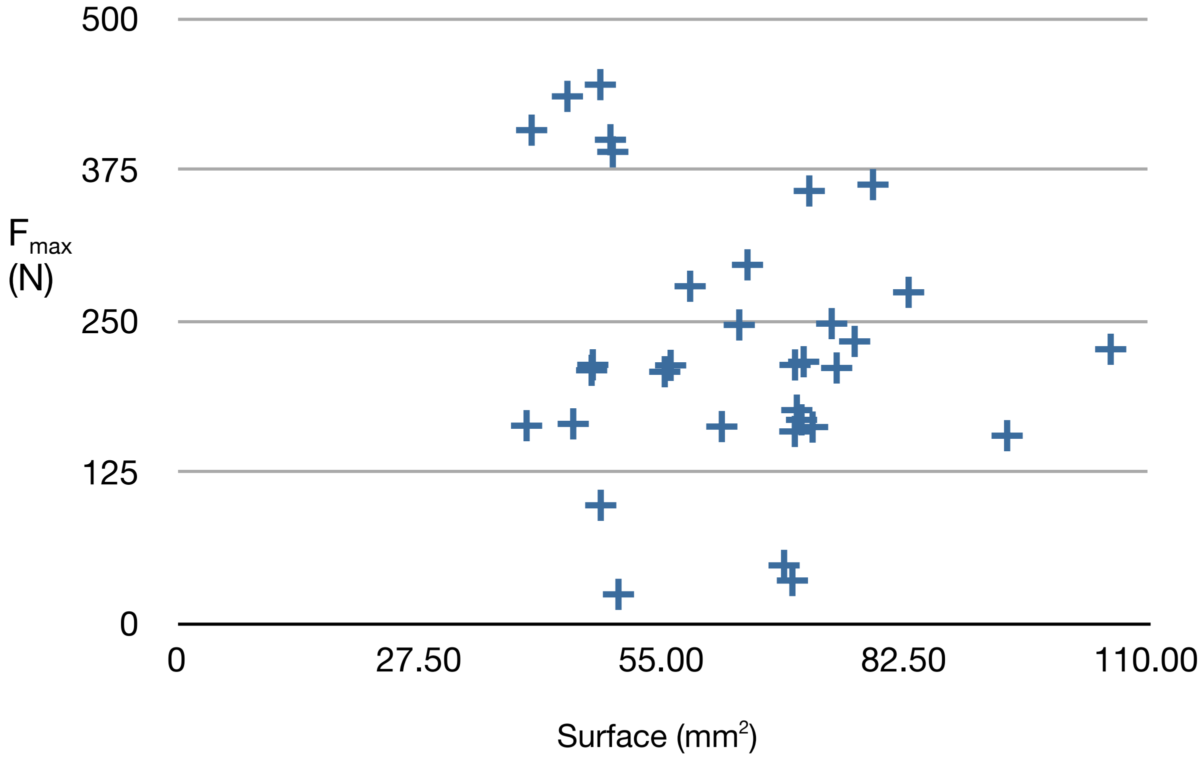
Table 6. Group III - Cumulative failure classes (and subclasses).

Substrate	*Failure class* a	b	c	d
	13			3
Dentin		7	0	
Dentin+Composite		0	1	
Composite		6	3	

Graphic 5. Group III - maximum reached tractional forces.



Graphic 6. Group III - Estimated dentin adhesive surfaces in relation to the maximum reached tractional forces.



Graphic 7. Statistical analysis – F_{max} (N) split by group

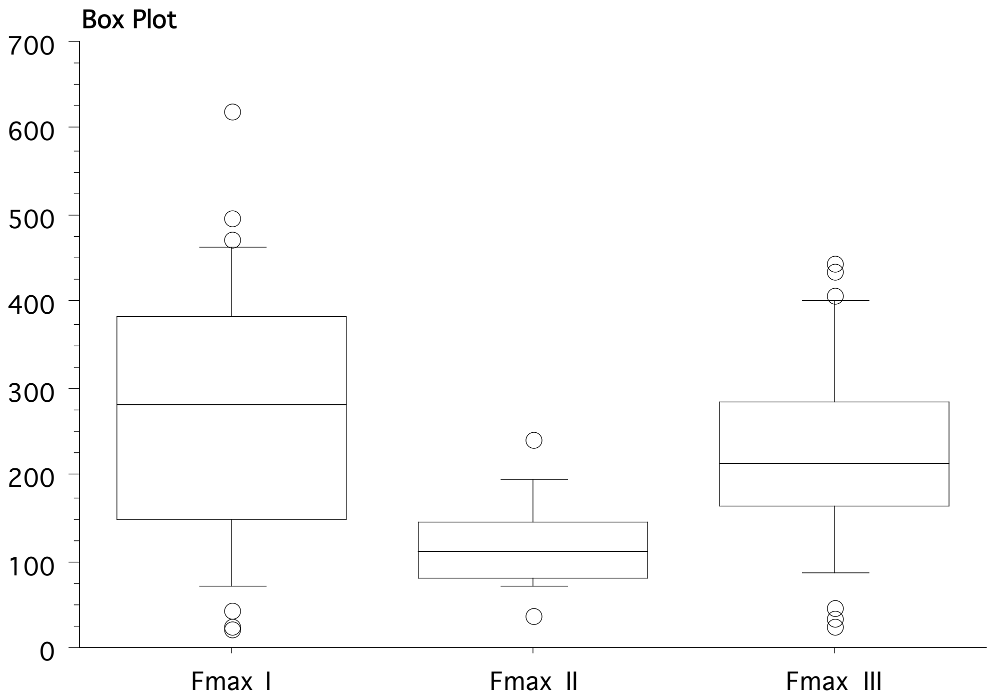


Table 7. Descriptive statistic – F_{max} (N) split by group

Descriptive Statistics

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	Median
Fmax I	274.172	147.140	25.614	33	22.660	620.340	280.720
Fmax II	119.780	54.277	14.014	15	36.040	241.910	109.720
Fmax III	230.221	109.857	19.124	33	23.810	445.160	213.470

Table 8. ANOVA Table for F_{max}.

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Group	2	246177.466	123088.733	8.570	.0004	17.141	.973
Residual	78	1120250.010	14362.180				

Table 9. Scheffe for F_{max}. Effect: Group. Significance Level: 5%

	Mean Diff.	Crit. Diff.	P-Value	
Groups I, III	-43.950	73.625	.3348	
Groups III, II	110.441	93.130	.0158	S
Groups I, II	154.392	93.130	.0004	S

Graphic 8. Statistical analysis – Surface (mm^2) split by group

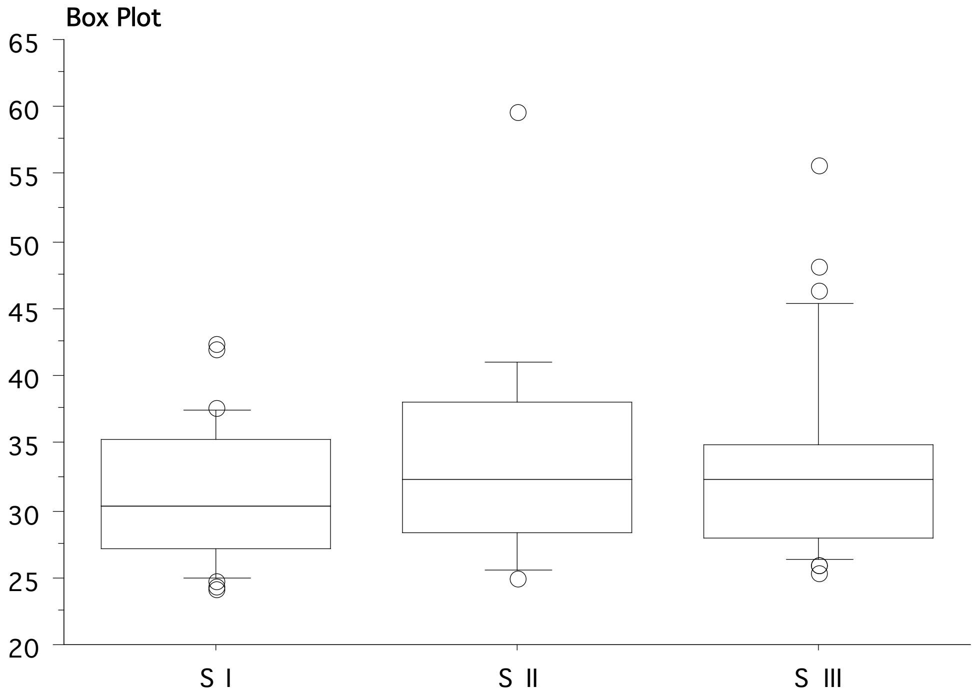
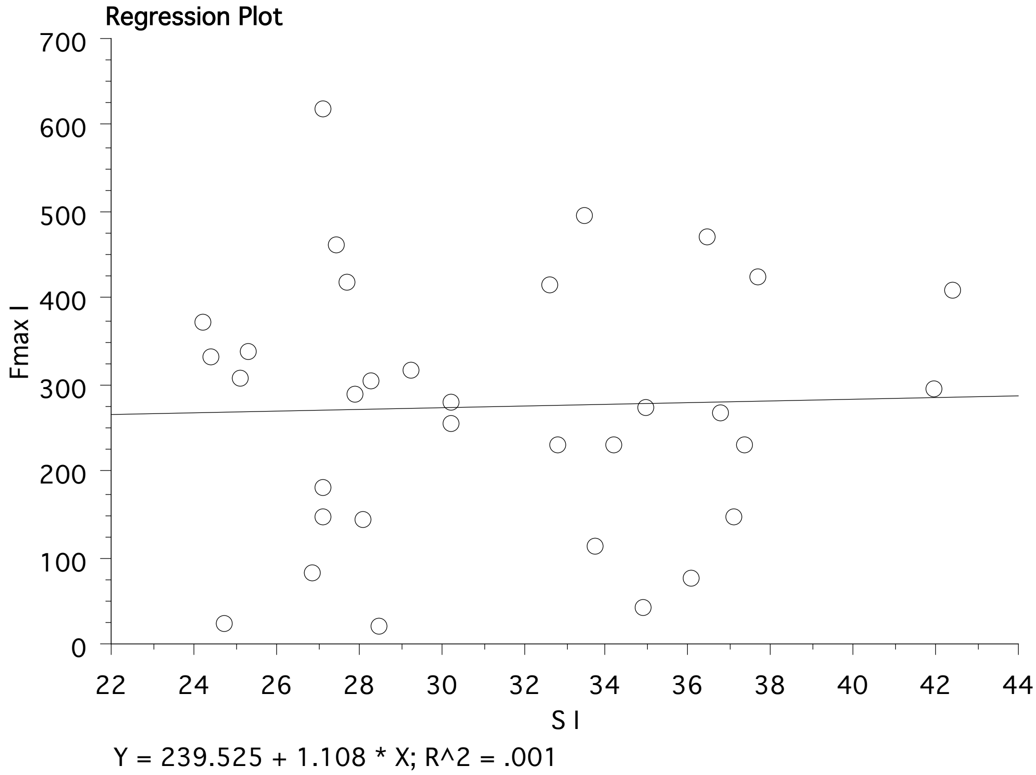


Table 10. Descriptive statistic – Surface (mm^2) split by group

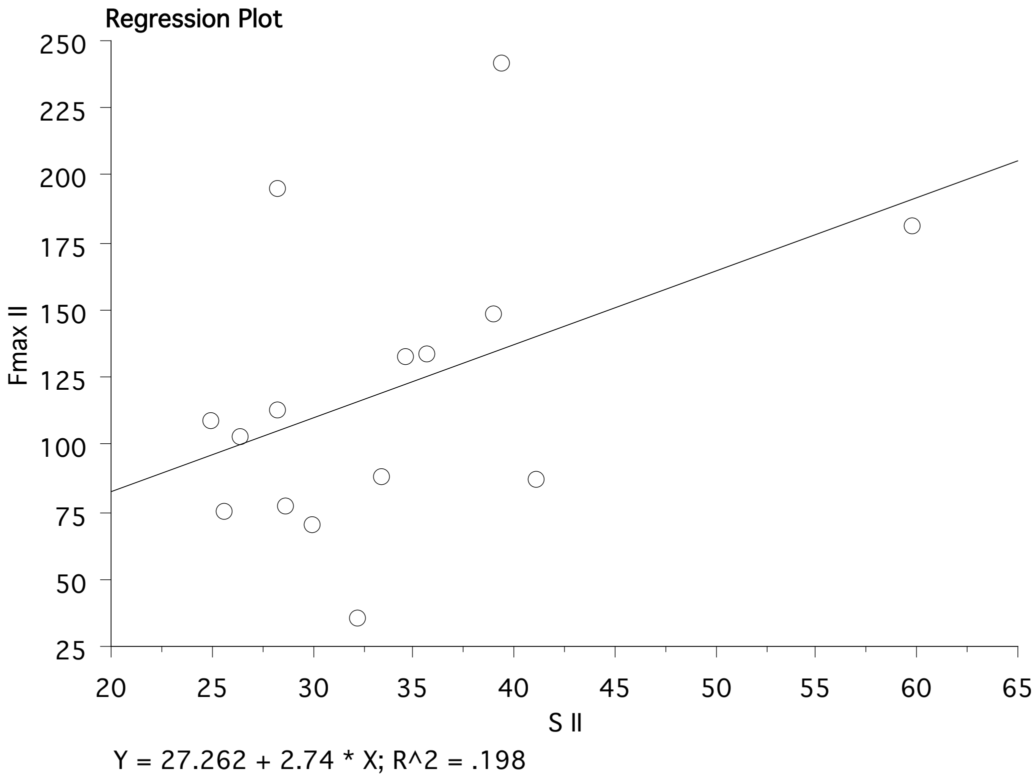
Descriptive Statistics

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	Median
S I	31.262	5.113	.890	33	24.180	42.390	30.220
S II	33.767	8.822	2.278	15	24.920	59.640	32.220
S III	33.175	7.007	1.220	33	25.280	55.590	32.380

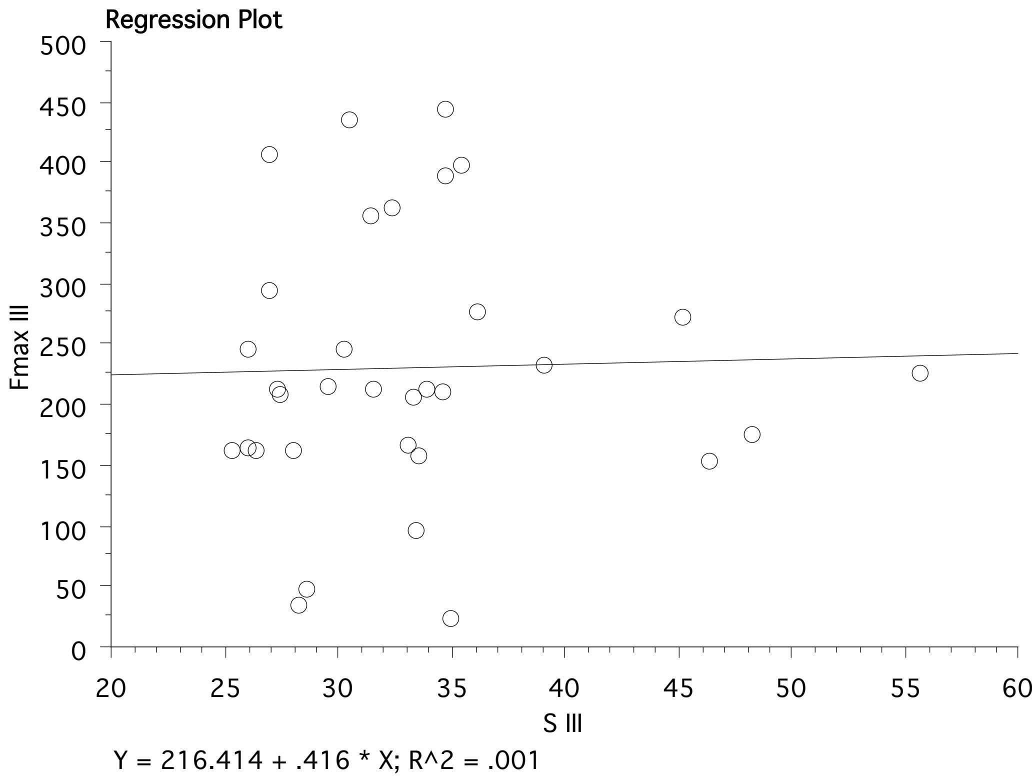
Graphic 9. Regression Plot, F_{max} vs surface (mm^2) – Group I



Graphic 10. Regression Plot, F_{max} vs surface (mm^2) – Group II



Graphic 11. Regression Plot, F_{max} vs surface (mm^2) – Group III



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